Investigating CPT violation with sterile neutrino fits

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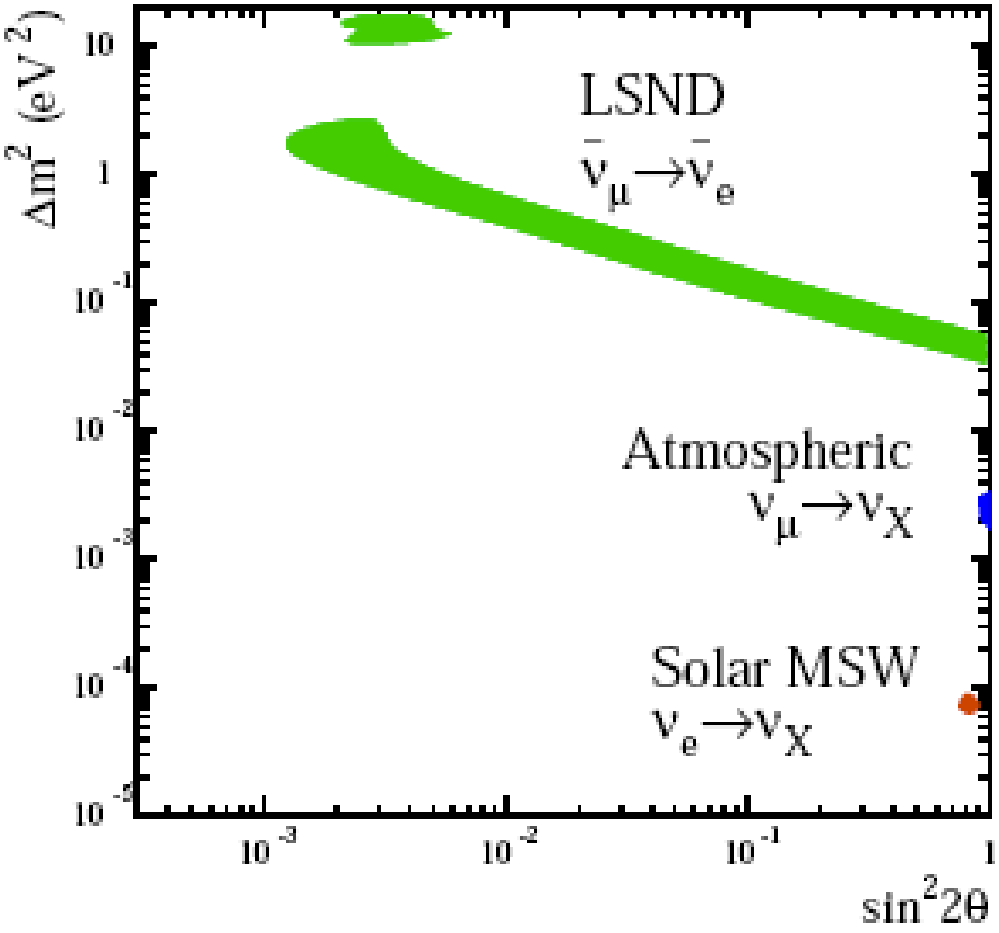
LSND



LSND result: Observed allowed region of Δm^2 not consistent with known mass splittings.

A 3rd mass splitting solves this problem

$\Delta m^2_{solar} \sim 10^{-5}$ eV^2

$\Delta m^2_{atm} \sim 10^{-3}$ eV^2

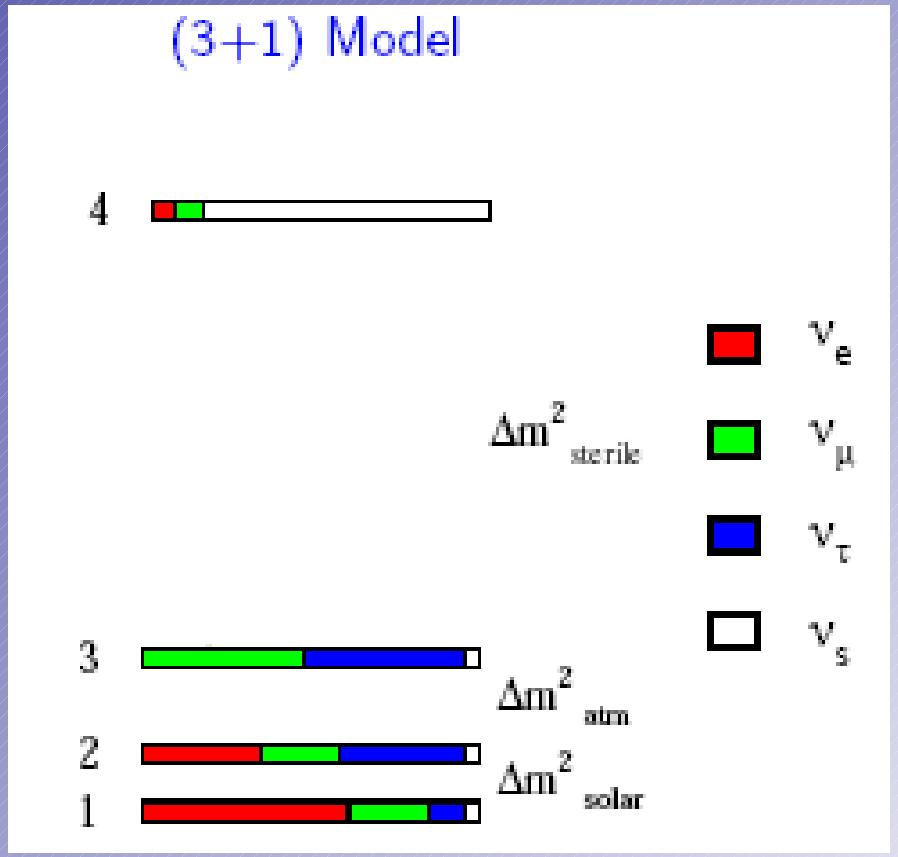
$\Delta m^2_{LSND} \sim 1$ eV^2

Sterile neutrinos

Don't interact through the weak force but can still oscillate with other neutrinos

Assume $\Delta m^2_{sterile}$ is much greater than Δm^2_{atm} and Δm^2_{solar} so only fit to one Δm^2 and one mixing parameter.

(So when we say 3+1 we really mean a 2 neutrino fit)



$$P(\nu_\alpha \rightarrow \nu_{\beta\neq\alpha}) = \sin^2 2\theta_{\alpha\beta} \sin^2[1.27(L/E)] \text{ (Appearance)}$$

$$P(\nu_\alpha \rightarrow \nu_\alpha) = \sin^2 2\theta_{\alpha\alpha} \sin^2[1.27(L/E)] \text{ (Disappearance)}$$

CP and CPT Violation

3+1 and 3+2 fits usually assume CPT conservation ($P_{dis}\nu = P_{dis}\bar{\nu}$)

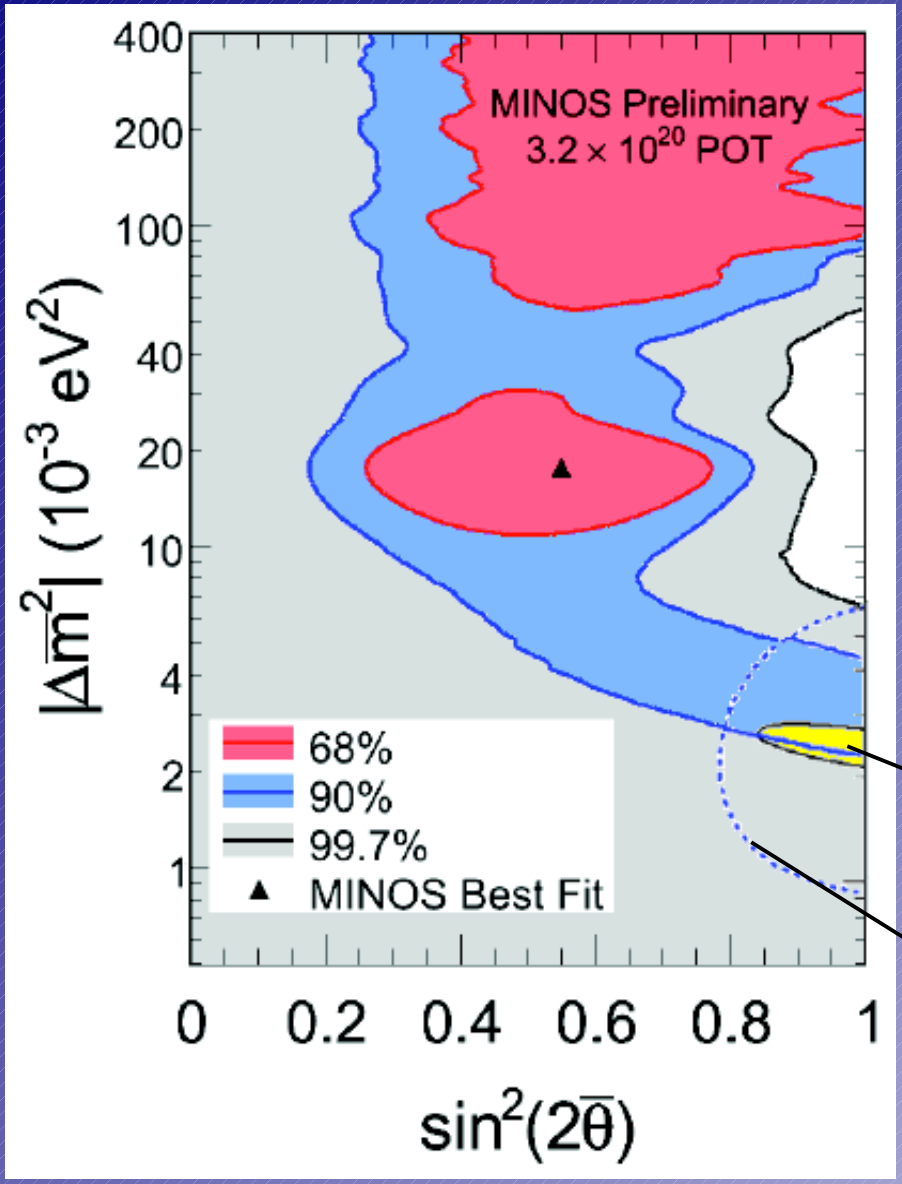
Occasionally introduce CP violation ($P_{app}\nu \neq P_{app}\bar{\nu}$) for better fits. CP violation is already known to occur in the weak interaction

CP violation can NOT explain ($P_{dis}\nu \neq P_{dis}\bar{\nu}$)

CPT violation would be bad for physics! It is one of the key principles of quantum field theory.

If observed, some lack of symmetry between $P_{dis}\nu$ and $P_{dis}\bar{\nu}$ could possibly be explained by new physics, such as a new type of interaction, which may save CPT conservation

MINOS Preliminary



MINOS favoring Δm^2 around 0.01 to ~0.4 eV^2 .

For ν, the best fit value from MINOS and other atmospheric experiments is known to lie at ~3 x 10^{-3} eV^2 with maximal mixing (~1)

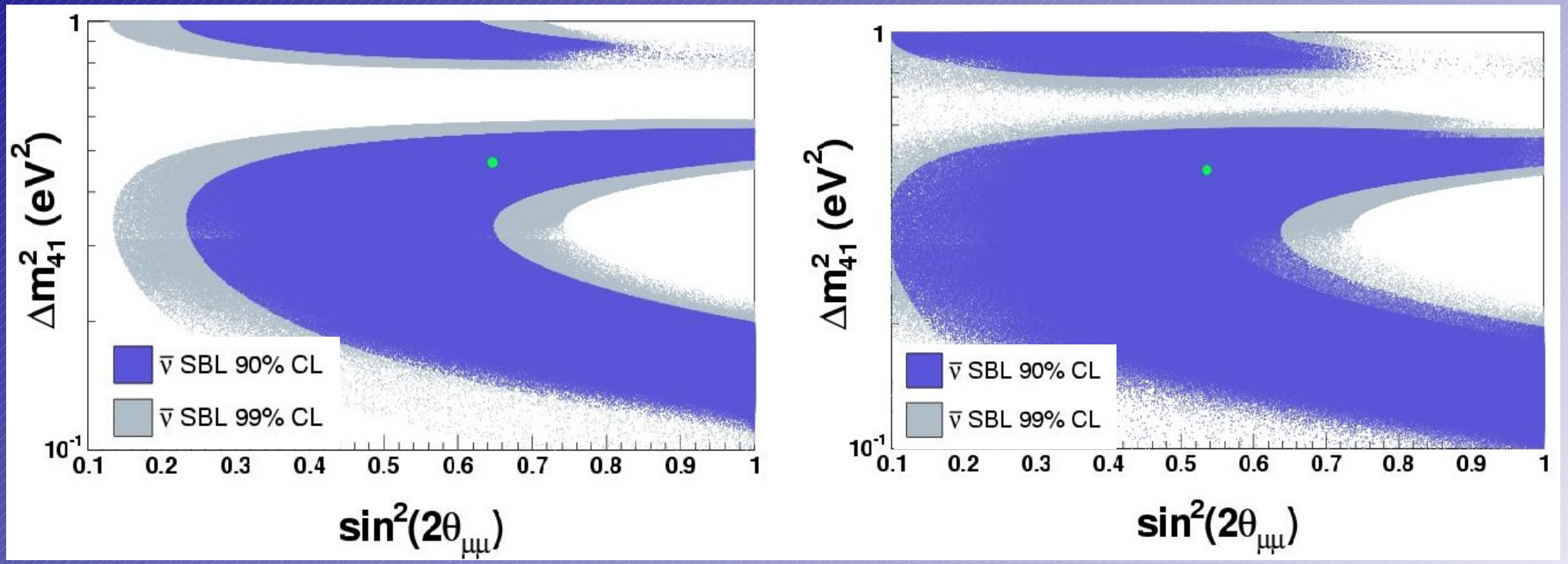
MINOS ν_μ 90%

Global ν 90%

MINOS – 3+1 Fit

Preliminary 3+1 fits indicate a preferred Δm^2_{41} around 0.5 eV^2

Don't have E_{true} and L_{true} information per event (data not yet released)



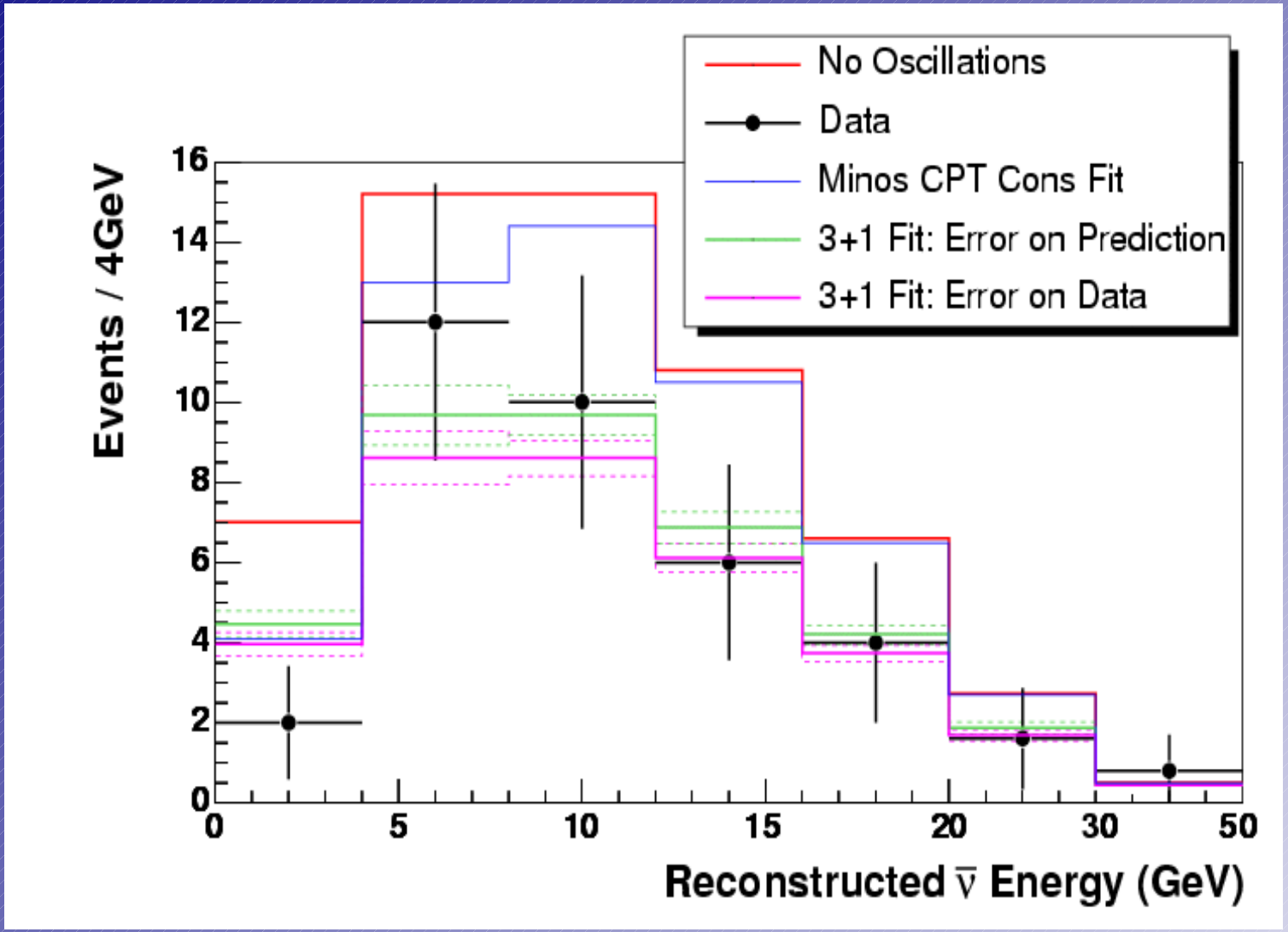
Fit with statistical error on data

Fit with statistical error on prediction

χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu\mu}$
3.8	5	57.9%	0.469	0.646

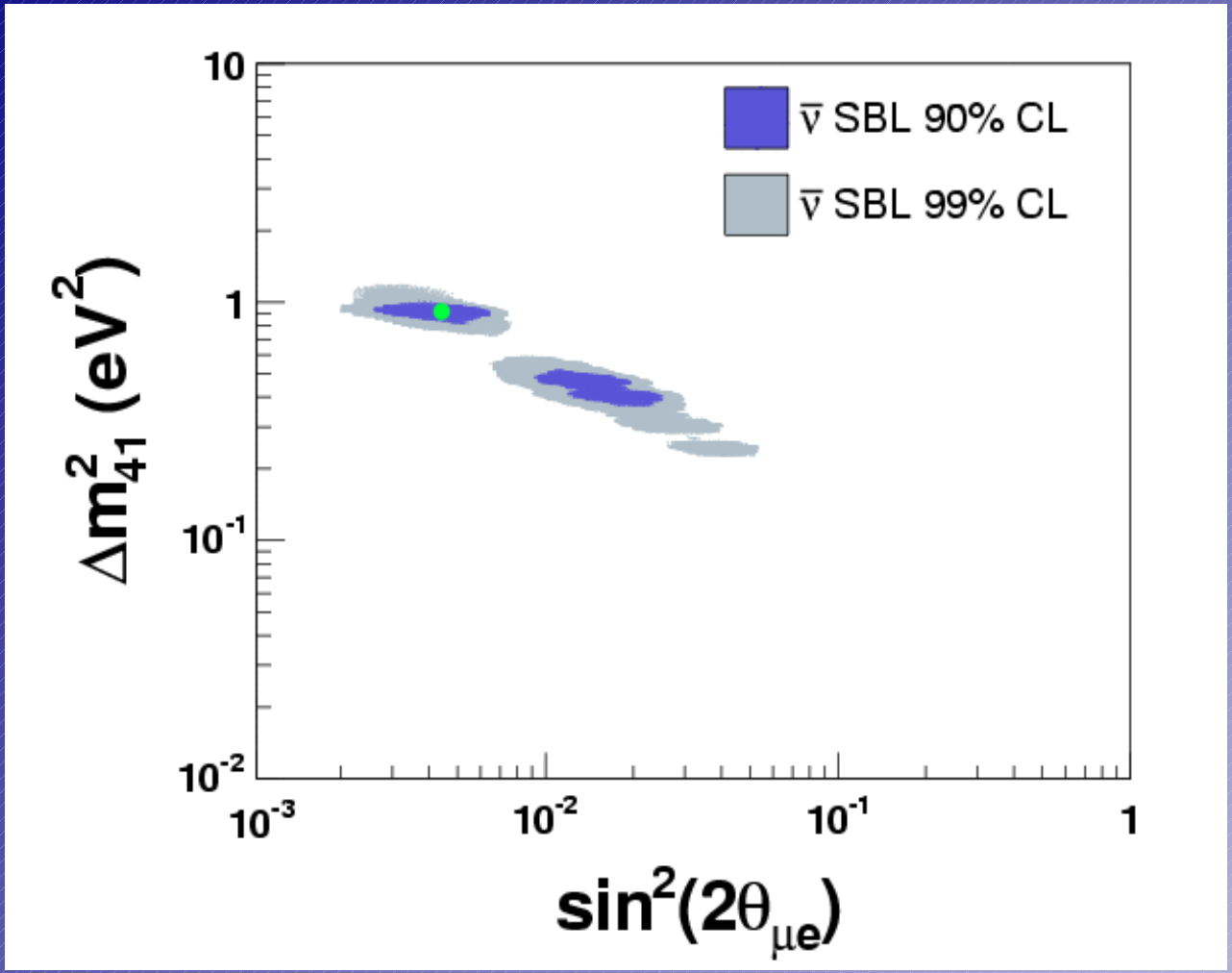
χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu\mu}$
3.4	5	63.9%	0.467	0.535

Fitting to (preliminary) MINOS data



MINOS data & fit from Fermilab wine and cheese (Jeff Hartnell – May 2009) plus some 3+1 fits

$\bar{\nu}$ only fit



Experiments included in fit:

MINOS *New!*

LSND

Miniboone $\bar{\nu}_e$

KARMEN

Bugey

Chooz

Best fit:

	χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu e}$	$\sin^2 2\theta_{\mu\mu}$
Before MINOS	87.9	103	86%	0.91	0.0043	0.350
With MINOS	92.26	110	89%	0.912	0.0044	0.405

MINOS data fits in nicely with previous $\bar{\nu}$ fit

ν only fit

From Karagiorgi et al. 2009 (arxiv:0906.1997v1)

Experiments included in fit:

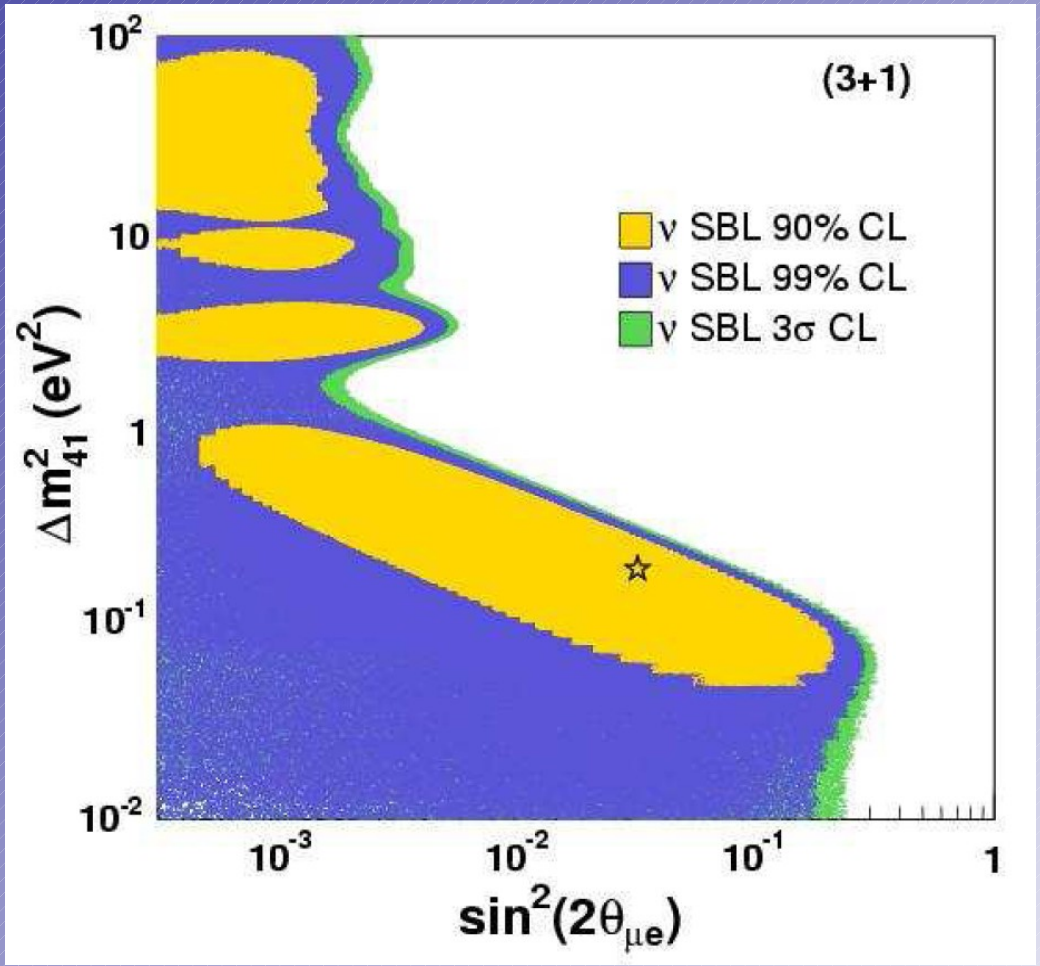
Miniboone ν_e

NOMAD

NuMI

CCFR84

CDHS

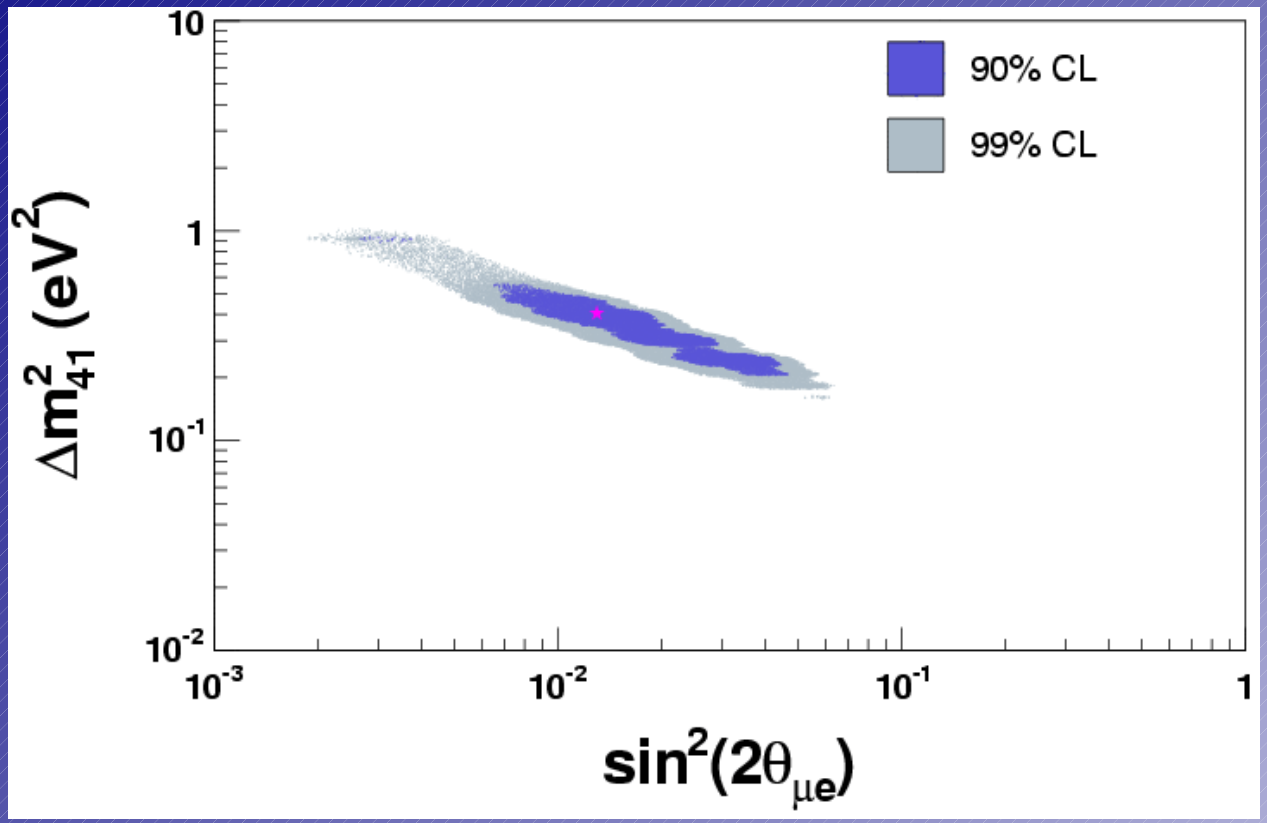


Best fit:

χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu e}$	$\sin^2 2\theta_{\mu\mu}$
90.5	90	47%	0.190	0.0310	0.0310

Looks different from $\bar{\nu}$ fit

Global 3+1 fit all experiments



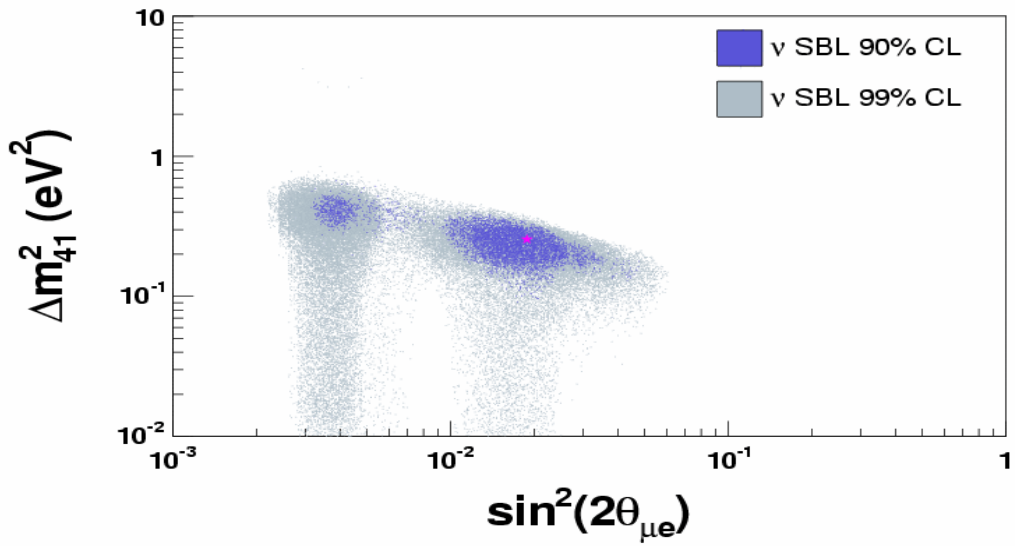
Experiments included in fit:

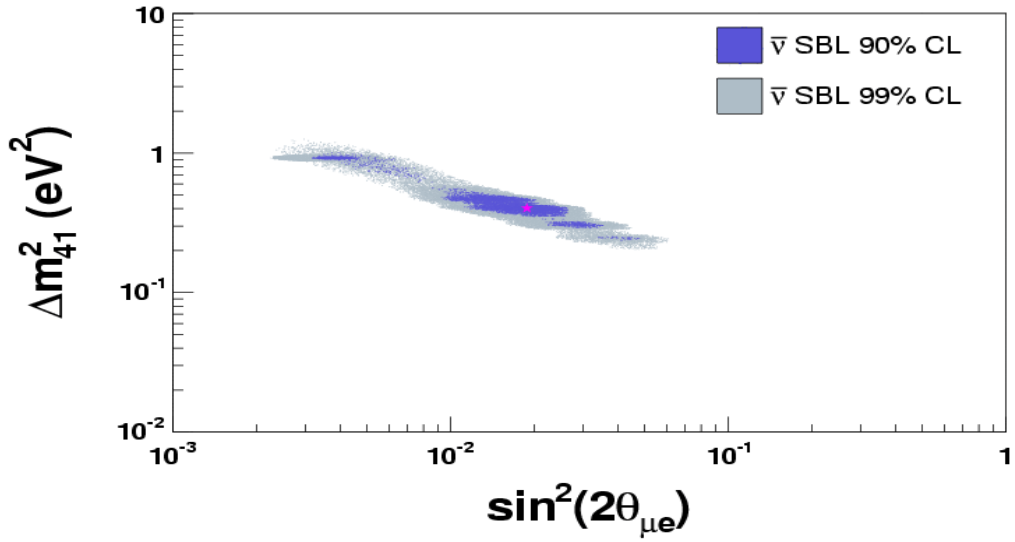
$\bar{\nu}$ experiments: MINOS *New!*, LSND, Miniboone $\bar{\nu}_e$, KARMEN, Bugey, Chooz

ν experiments: Miniboone ν_e, NOMAD, NuMI, CCFR84, CDHS, atmospheric constraint

	χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu e}$	$\sin^2 2\theta_{\mu\mu}$
Before MINOS	197.4	196	46%	0.920	0.0025	0.130
After MINOS	196.2	203	62%	0.403	0.0130	0.0904

Global fit – CPT Violating





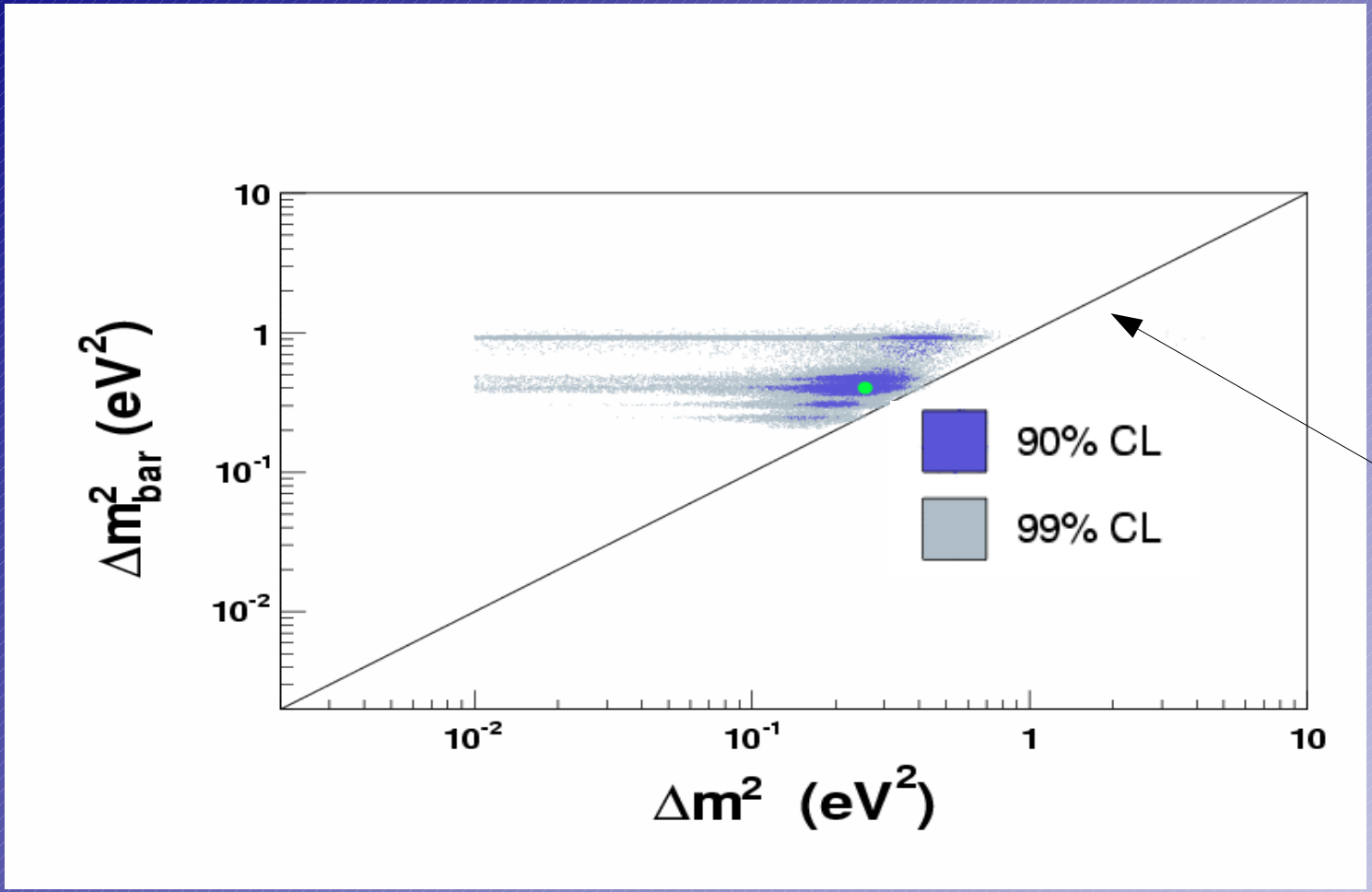
Allows Δm^2 to vary separately for neutrinos and antineutrinos

Not yet allowing mixing parameters to vary separately

Best fit:

χ^2	189.8
dof	204
Probability	75%
Δm^2	0.255
Δm^2_{bar}	0.402
$\sin^2 2\theta_{\mu e}$	0.0188
$\sin^2 2\theta_{\mu\mu}$	0.0899

$\Delta m^2_{\bar{\nu}}$ vs Δm^2_{ν}

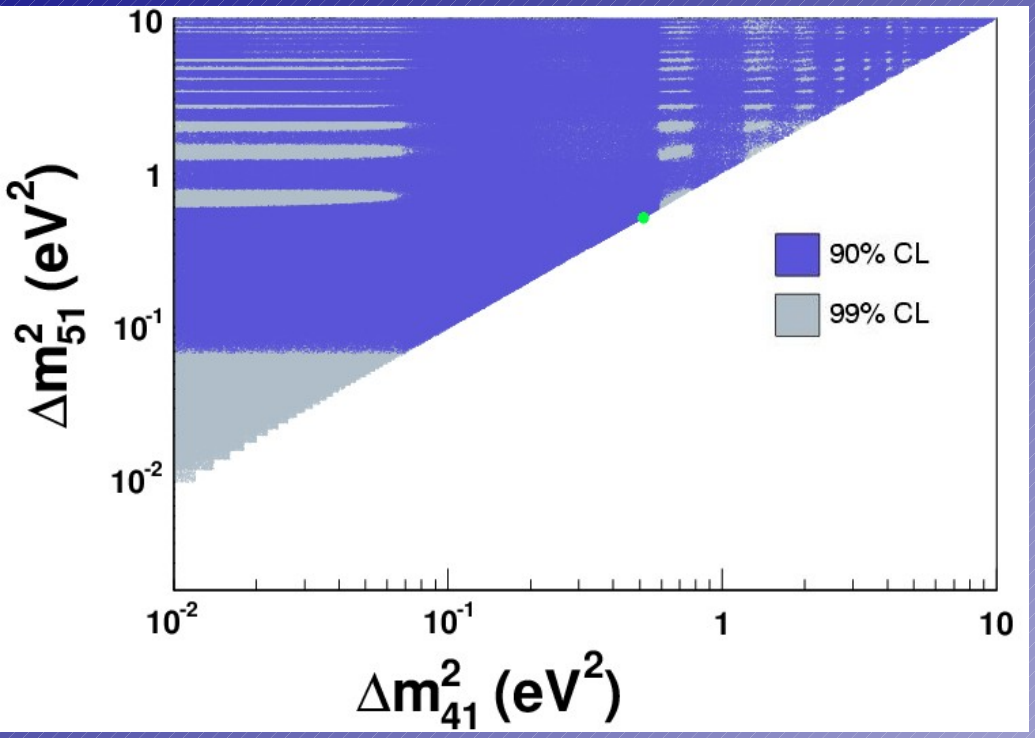


Points along line obey CPT

Best fit not along line

No 90% CL points along line either

3+2 Fit to MINOS



Best fit values:

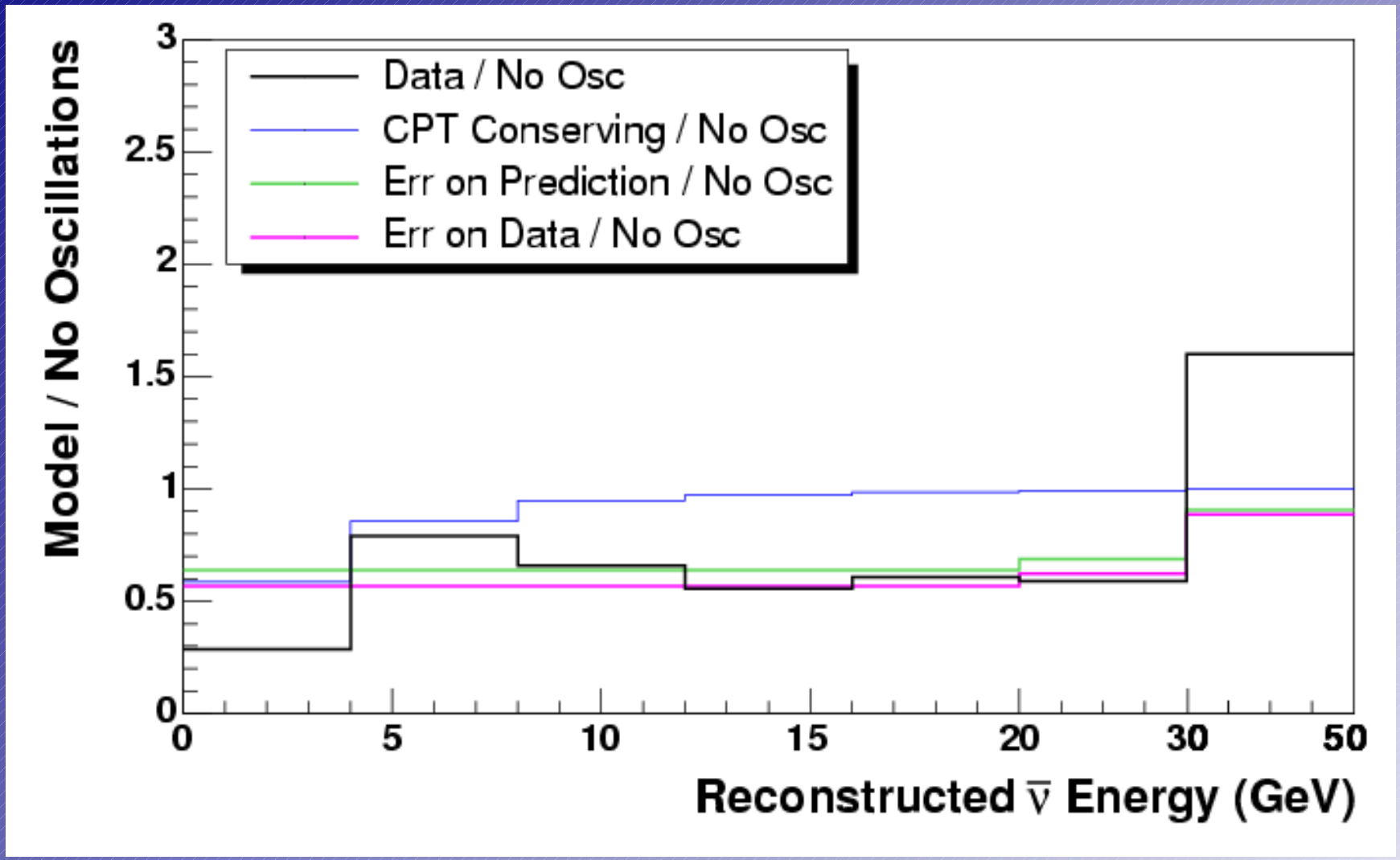
χ^2	dof	Probability	Δm^2_{41}	Δm^2_{51}
3.4	3	33%	0.463	0.467

Second Δm^2 not favored

Don't have near detector data or good energy info. It's possible things will change

Coming Soon...

- Full event sample for MINOS
- Allow Mixing parameters to vary separately too for CPT violating fits
- Including the new MiniBooNE ν_μ and $\overline{\nu}_\mu$ disappearance data


Data / No Osc
CPT Conserving / No Osc
Err on Prediction / No Osc
Err on Data / No Osc
Model / No Oscillations
Reconstructed $\bar{\nu}$ Energy (GeV)
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
30
50